



- (51) **International Patent Classification:**
A61B 6/02 (2006.01) *G06T 11/00* (2006.01)
G01T 1/29 (2006.01)
- (21) **International Application Number:** PCT/US2016/038476
- (22) **International Filing Date:** 21 June 2016 (21.06.2016)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:** 201510979160.X 23 December 2015 (23.12.2015) CN
- (71) **Applicant:** **GENERAL ELECTRIC COMPANY** [US/US]; 1 River Road, Schenectady, New York 12345 (US).
- (72) **Inventors:** **WANG, Xueli**; General Electric Company, No. 2 Yong Chang Road, Beijing 100176 (CN). **CAO, Ximiao**; General Electric Company, No. 2 Yong Chang Road, Beijing 100176 (CN).
- (74) **Agents:** **DIVINE, Lucas** et al.; General Electric Company, 9900 W Innovation Drive, Wauwatosa, Wisconsin 53226 (US).
- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH,

[Continued on next page]

(54) **Title:** APPARATUS AND METHOD FOR DATA RECOVERY OF RAW CT PROJECTION DATA AND CT IMAGING SYSTEM

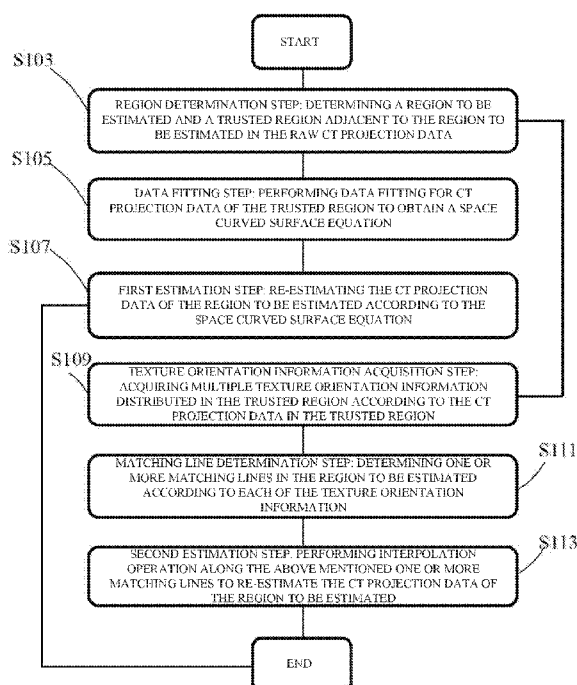


FIG. 1

(57) **Abstract:** The present invention provides a method for data recovery of raw CT projection data, comprising: determining a region to be estimated and a trusted region adjacent to the region to be estimated in raw CT projection data; and performing at least one of a first processing and a second processing. The first processing comprises: performing data fitting for CT projection data of the trusted region to obtain a space curved surface equation; re-estimating CT projection data of the region to be estimated according to the space curved surface equation. Said second processing comprises: acquiring multiple texture orientation information distributed in the trusted region according to the CT projection data of the trusted region; determining one or more matching lines in the region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information; performing interpolation operation along the matching lines, to re-estimate the CT projection data of the region to be estimated.



GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT,
LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE,

SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA,
GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

APPARATUS AND METHOD FOR DATA RECOVERY OF RAW CT PROJECTION DATA AND CT IMAGING SYSTEM

FIELD

[0001] The present invention relates to the field of X-Ray imaging and, in particular, relates to a method and an apparatus for data recovery of raw CT projection data as well as a CT imaging system.

BACKGROUND

[0002] In medical imaging technique of Computed Tomography (CT), raw data collected from a detector is arranged into a two-dimensional matrix with a horizontal axis of detector channel and a vertical axis of scan field of view as raw CT projection data of the reconstructed image, which is also referred to as a sinogram and is essentially a winding superimposition of curves formed by the points on the image. For example, if the collected CT projection data is reconstructed as an image with a size of 512×512 , then any point on the image is a curve trace in the matrix of the raw CT projection data. The amplitude of the curve trace depends on a distance of the point from a center of rotation for virtual collection, in which the greater the distance, the greater the amplitude. The phase of the curve trace depends on a position of the point on a certain circle with the center of rotation as the center of the circle.

[0003] Data of low credibility is often present in the raw CT projection data, which may be caused by several reasons, for example, temporary failure or failure during the entire collection process of some detector channel, data abnormality of some field of view, data fall due to bulb tube ignition, incredible data on the corresponding curve trace due to the metal in the body of the detected object and the like. Thus, when performing CT image reconstruction, data compensation or recovery usually needs to be performed for the raw data, for example, sometimes encryption also needs to be performed for data between neighboring fields of view or neighboring

detector channels, or repairing also needs to be performed for data with large spacing between channels and the like.

[0004] Traditional data compensation operations are all based on interpolation within the detector row or interpolation between channels with the same opening angle between the detector rows. The quality of the reconstructed images thereby cannot be efficiently enhanced and sometimes good and sometimes bad characteristic are exhibited for different objects to be scanned.

SUMMARY

[0005] One object of the present invention is to provide a method and an apparatus that can recover CT raw projection data more accurately, as well as a CT imaging system employing the apparatus.

[0006] An exemplary embodiment of the present invention provides a method for data recovery of raw CT projection data, comprising: determining a region to be estimated and a trusted region adjacent to the region to be estimated in raw CT projection data; and performing at least one of a first processing and a second processing. The first processing comprises: performing data fitting for CT projection data of the trusted region to obtain a space curved surface equation; and re-estimating CT projection data of the region to be estimated according to the space curved surface equation. Said second processing comprises: acquiring multiple texture orientation information distributed in the trusted region according to the CT projection data of the trusted region; determining one or more matching lines in the region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information; performing interpolation operation along the matching lines, to re-estimate the CT projection data of the region to be estimated.

[0007] An exemplary embodiment of the present invention further provides an apparatus for data recovery of raw CT projection data, comprising a region determination module and at least one of a first processing module and a second

processing module. The region determination module is to determine a region to be estimated and a trusted region adjacent to the region to be estimated in the raw CT projection data. Said first processing module comprises a data fitting unit and a first estimation unit. The data fitting unit is to perform data fitting for the CT projection data of the trusted region to obtain a space curved surface equation. The first estimation unit is to re-estimate the CT projection data of the region to be estimated according to the space curved surface equation. The second processing module comprises a texture orientation information acquisition unit, a matching line determination unit and a second estimation unit. The texture orientation information acquisition unit is to acquire multiple texture orientation information distributed in the trusted region according to the CT projection data of the trusted region; the matching line determination unit is to determine one or more matching lines in the region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information; the second estimation unit is to perform interpolation operation along said one or more matching lines, to re-estimate the CT projection data of the region to be estimated.

[0008] An exemplary embodiment of the present invention further provides a CT imaging system, comprising a bulb tube to emit X-rays to an object to be scanned, a detector to receive the X-rays that pass through the object to be scanned to generate said raw CT projection data and an apparatus for data recovery of CT raw projection data as stated above.

[0009] Other features and aspects will be apparent through the following detailed description, figures and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present invention can be understood better in light of the description of exemplary embodiments of the present invention with reference to the accompanying drawings, in which:

[0011] Fig. 1 is a flow chart of a method for correcting CT image provided by one embodiment of the present invention;

[0012] Fig. 1 is a flow chart of a method for data recovery of raw CT projection data provided by a first embodiment of the present invention;

[0013] Fig. 2 is the raw CT projection data acquired in one exemplary embodiment of the present invention;

[0014] Fig. 3 is a schematic diagram of determining a matching line in a region to be estimated according to texture orientation information of CT projection data of a trusted region, in one exemplary embodiment of the present invention;

[0015] Fig. 4 is a flow chart of a method for data recovery of raw CT projection data provided by a second embodiment of the present invention;

[0016] Fig. 5 is a block diagram of an apparatus for data recovery of raw CT projection data provided by a third embodiment of the present invention;

[0017] Fig. 6 is a block diagram of an apparatus for data recovery of raw CT projection data provided by a fourth embodiment of the present invention;

[0018] Fig. 7 is a block diagram of a CT imaging system provided by a fifth embodiment of the present invention.

DETAILED DESCRIPTION

[0019] Hereafter, a detailed description will be given for preferred embodiments of the present disclosure. It should be pointed out that in the detailed description of the embodiments, for simplicity and conciseness, it is impossible for the Description to describe all the features of the practical embodiments in details. It should be understood that in the process of a practical implementation of any embodiment, just as in the process of an engineering project or a designing project, in order to achieve a specific goal of the developer and in order to satisfy some system-related or business-related constraints, a variety of decisions will usually be made, which will also be varied from one embodiment to another. In addition, it can also be

understood that although the effort made in such developing process may be complex and time-consuming, some variations such as design, manufacture and production on the basis of the technical contents disclosed in the disclosure are just customary technical means in the art for those of ordinary skilled in the art associated with the contents disclosed in the present disclosure, which should not be regarded as insufficient disclosure of the present disclosure.

[0020] Unless defined otherwise, all the technical or scientific terms used in the Claims and the Description should have the same meanings as commonly understood by one of ordinary skilled in the art to which the present disclosure belongs. The terms "first", "second" and the like in the Description and the Claims of the present utility model do not mean any sequential order, number or importance, but are only used for distinguishing different components. The terms "a", "an" and the like do not denote a limitation of quantity, but denote the existence of at least one. The terms "comprises", "comprising", "includes", "including" and the like mean that the element or object in front of the "comprises", "comprising", "includes" and "including" covers the elements or objects and their equivalents illustrated following the "comprises", "comprising", "includes" and "including", but do not exclude other elements or objects. The term "coupled" or "connected" or the like is not limited to being connected physically or mechanically, nor limited to being connected directly or indirectly.

[0021] First Embodiment

[0022] Fig. 1 is a flow chart of a method for data recovery of raw CT projection data provided by a first embodiment of the present invention. A skilled person in the art would understand that the above mentioned raw CT projection data may be, for example, projection data collected from a detector channel of the CT imaging system, or projection data subjected to some pre-processing after being collected, in which the pre-processing may comprise, by way of example, removing dark current by offset correction, removing fluctuation of radial energy in respective fields of view by reference channel correction, removing non-uniformity of initial incoming energy of respective channels by aircal correction, removing inconsistency in absorption

between high and low energy rays by beam hardening correction, converting data into summations in theory by $-\ln$ mathematical transformation, and so on.

[0023] Fig. 2 is the raw CT projection data acquired in one exemplary embodiment of the present invention. The horizontal axis in Fig.2 denotes the detector channel and the vertical axis in Fig.2 denotes the scan field of view. Each data point in the raw CT projection data is a superimposition of data collected in corresponding scan fields of view by corresponding detection channels.

[0024] As shown in Fig.1, the method for data recovery of raw CT projection data comprises the following steps:

[0025] A region determination step S103: determining a region to be estimated and a trusted region adjacent to the region to be estimated in the raw CT projection data. As shown in Fig.2, as the raw CT projection data may have a region with data of low credibility, the CT projection data of each point in the region needs to be re-estimated so as to perform image reconstruction more precisely. The region with low credibility is just the region to be estimated. For example, the region A in Fig.2 may be determined as a region to be estimated, through observation by naked-eye or data analysis by computer or the like. And regions B1 and/or B2 with relatively high data credibility adjacent to the region A may be determined as trusted regions. It should be noted that the above determined trusted region and region to be estimated are not limited in their shape or size.

[0026] After determining the region to be estimated and the trusted region, data recovery may be performed for the region to be estimated with data characteristics of the trusted region, for example, at least one of a first processing and a second processing may be performed. The data characteristics of the trusted region may comprise, for example, CT projection values and coordinate values of the data points, texture orientation information of the trusted region and so on, in which the above mentioned texture orientation information may represent, e.g., texture orientation of the curve traces in the trusted regions B1, B2 in Fig.2.

[0027] The above mentioned first processing comprises a data fitting step S105 and a first estimation step S107.

[0028] The data fitting step S105: performing data fitting for the CT projection data of the trusted region to obtain a space curved surface equation.

[0029] The first estimation step S107: re-estimating the CT projection data of the region to be estimated according to the above mentioned space curved surface equation.

[0030] For example, data fitting may be performed for the CT projection data in the trusted regions B1 and B2 in Fig.2, and the above mentioned data fitting may comprise, e.g., least square data fitting.

[0031] Optionally, in the first estimation step S107, re-estimating the CT projection data of the region to be estimated according to the space curved surface equation comprises: taking coordinates and CT projection values of a data point to be estimated in the region to be estimated as input values for the above mentioned space curved surface equation, and calculating output values of the space curved surface equation as a low-frequency part of the new CT projection data of the data point.

[0032] In particular, the low-frequency data in the CT projection data of the trusted region may be acquired prior to data fitting, for example, the low-frequency data in the raw CT projection data may be acquired by performing low-pass filtering for the raw CT projection data. Then in the data fitting step S105, data fitting may be performed for the low-frequency part of the CT projection data of the trusted region to obtain the space curved surface equation.

[0033] The above mentioned second processing comprises a texture orientation information acquisition step S109, a matching line determination step S111, a second estimation step S113.

[0034] The texture orientation information acquisition step S109: acquiring multiple texture orientation information distributed in the trusted region according to the CT projection data in the trusted region.

[0035] The matching line determination step S111: determining one or more matching lines in the region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information.

[0036] The second estimation step S113: performing interpolation operation along the above mentioned one or more matching lines, to re-estimate the CT projection data of the region to be estimated.

[0037] After performing interpolation operation along each of the matching lines, if there are multiple interpolation results for each data point to be estimated (for example, there are multiple matching lines passing through the same data point to be estimated), the multiple interpolation results are summed as the final interpolation result of the data point.

[0038] A skilled person in the art may understand that each of the above mentioned texture orientation information can represent texture trend of the curve trace at the corresponding data point. Fig.3 is a schematic diagram of determining a matching line in a region to be estimated according to texture orientation information of CT projection data of a trusted region, in one exemplary embodiment of the present invention. As shown in Fig.3, for the curve trace on the CT projection data, since its coordinates (or data points) vary continuously, its texture orientation information may comprise multiple specific directions along the curve trace. Each of the specific directions may be represented in a number of forms, for example, only in the form of stored data (such as angle, slope and the like of the curve trace at the corresponding coordinate position), or may also be represented by respective directional lines L1 shown in Fig.3, wherein each directional line L1 has a specific direction, i.e. has a specific angle or slope, representing that there is a curve trace in the direction pointed by the directional line L1, or may be understood as: the

directional line L is a part of a certain complete curve trace. For any curve trace, if all corresponding directional lines L1 thereof are known and the overall trend of the curve trace may be obtained by connecting these directional lines L1 in turn, the directional lines may be lines with a relatively short length. A skilled person in the art may understand that texture orientation information represented in other forms may also be acquired as long as it can represent the trend of the curve trace on the CT projection data.

[0039] Optionally, the texture orientation information acquisition step S109 may comprise: acquiring multiple texture orientation information distributed in the trusted region according to the high-frequency data in the CT projection data of the trusted region. In particular, the high-frequency data in the CT projection data of the trusted region may be acquired first prior to acquiring the texture orientation information, to acquire the corresponding texture orientation information according to the high-frequency data.

[0040] The high-frequency data in the CT projection data of the trusted region may be acquired through the following two ways: one may be calculating the low-frequency data of the CT projection data of the trusted region according to the space curved space equation obtained in the data fitting step S105 (for example, taking the coordinates and the CT projection values of the data points to be estimated of the trusted region as input values to be introduced into the space curved surface equation and using the output values as the corresponding low-frequency data), and subtracting the low-frequency data of the CT projection data of the trusted region calculated according to the space curved surface equation from the raw CT projection data of the trusted region, to obtain the corresponding high-frequency data; the other one may be performing filtering and strengthening for the raw CT projection data to obtain the raw high-frequency data, wherein the above high-frequency data in the CT projection data of the trusted region may be determined from the raw high-frequency data directly.

[0041] Optionally, the texture orientation information acquisition step S109 may comprise: filtering the CT projection data of the trusted region with a filter to acquire

multiple texture orientation information distributed in the trusted region. When filtering the CT projection data of the trusted region with a filter, filtering may be performed for only the raw CT projection data in the trusted region or for only the high-frequency part therein; filtering may also be performed for the raw CT projection data in the whole data region or the high-frequency part therein to obtain the texture orientation information on the whole data region, and the texture orientation information distributed in the trusted region may be determined directly from the texture orientation information of the whole data region.

[0042] The above mentioned filter may comprise a Gabor filter, for example, Gabor filters of multiple directions may be generated. Said Gabor filters of multiple directions are used to filter the data to be filtered in the corresponding directions, and the directional result of each Gabor filter is just the highest amplitude of the Gabor filtering response at each data point, i.e., the above mentioned respective texture orientation information. The texture orientation information obtained with the Gabor filters may comprise multiple directional lines as shown in Fig.3.

[0043] Of course, filters in other forms may also be used as long as the texture orientation information of the CT projection data can be obtained.

[0044] Optionally, the matching line determination step S111 may comprise a straight line determination step and a matching step:

[0045] The straight line determination step: determining, for each data point to be estimated, one first straight line passing through the data point.

[0046] The matching step: if the first straight line can rotate about the data point as a center of rotation to a matching angle, the first straight line at the matching angle is determined as one matching line. Specifically, at the matching angle, the angles formed by connecting the first straight line with at least two directional lines are less than or equal to a preset angle respectively. The above mentioned at least two directional lines are located at opposite sides of the data point to be estimated. The matching precision may be adjusted by adjusting the above preset angle; for

example, if the preset angle is set to be 0, only one first straight line that is exactly in line with two directional lines at opposite sides of the data point P1 can be considered as the matching line.

[0047] By way of example, as a specific example, one straight line L1 may be at first determined with a horizontal angle or another angle as a starting point for the data point P1 in Fig.3, and the first straight line may be rotated about the data point P1 as a center of rotation within 360 degrees. If the straight line L1 is approximately in line with the directional lines D1 and D2 at opposite sides of the data point P1 after being rotated 30 degree, one matching line can be determined at the orientation of 30 degree; if the straight line L1 is approximately in line with the directional lines D3 and D4 at opposite sides of the data point P1 after being rotated 150 degree, one matching line can be determined at the orientation of 150 degree. Of course, in some situations, if the straight line L1 is only approximately in line with the directional line D1 at one side of the data point P1 while is at a too large angle with respect to the directional line D2 at the other side of the data point P1 after being rotated 30 degree, the straight line L1 may also be determined as the matching line. That is, it is only required that each matching line is matched with at least one texture orientation information.

[0048] Apparently, in the matching line determination step S111, in order to be matched with the texture trend of the curve trace in the trusted region, the matching lines determined in the region to be estimated are not along the detecting channel direction or not all of them are along the detecting channel direction, i.e., are not horizontal lines or vertical lines or not all of them are horizontal lines or vertical lines, and they may be oblique lines. The matching line may be understood as representing the trend of the curve trace in the region to be estimated, which, for example, can smoothly be connected to one curve trace matched therewith in the trusted region.

[0049] Thus, in the second estimation step S113, interpolation operation along the curve trace is realized instead of interpolation within the channel row or interpolation

between channels with the same opening angle between rows. In this way, the recovered data is more precise and quality of the acquired CT image is better.

[0050] Second Embodiment

[0051] Fig.4 is a flow chart of a method for data recovery of raw CT projection data provided by a second embodiment of the present invention, which is similar to the first embodiment except that: in the second embodiment, the above mentioned second processing may further comprise a comparison step S115 and a matching line classification step S117.

[0052] The comparison step S115: comparing a data intensity at a data point corresponding to the texture orientation information (e.g., directional lines D1 and/or D2) matched with each matching line with a preset data intensity;

[0053] The matching line classification step S117: if the data intensity at the data point corresponding to the texture orientation information matched with anyone of the matching line is greater than or equal to the preset data intensity, the corresponding matching line is determined as the first matching line; otherwise, if the data intensity at the data point corresponding to the texture orientation information (e.g., directional lines D1 and/or D2) matched with any matching line is less than the preset data intensity, the corresponding matching line is determined as the second matching line.

[0054] At this moment, in the second estimation step S113, performing interpolation operation along the above mentioned one or more matching lines comprises: only choosing to perform interpolation operation along the first matching line. For the second matching line, it may be ignored. Performing interpolation operation only along the first matching line may be understood as: searching for a trace matched with the curve trace having a relatively high data intensity in the region to be estimated and performing interpolation operation along the trace. The above mentioned data intensity means an absolute value of the CT projection value at the corresponding data point. In the above manner, not only computation of the

interpolation operation is reduced, but also the accuracy of data recovery is increased.

[0055] In order to reduce workload of data recovery, the method may only perform the first processing or only perform the second processing. For example, data fitting may be performed only for the low-frequency data to re-estimate the low-frequency part of the CT projection data of the region to be estimated, or interpolation operation may be performed only for the high-frequency data along a matching line after the matching line is determined in the region to be estimated.

[0056] In the second embodiment, in order to ensure the accuracy of data recovery, the method for data recovery of raw CT projection data of the present invention may comprise the above mentioned first processing and second processing and may further comprise summation processing step S119: performing summation for the CT projection data estimated in the first estimation step and the CT projection data estimated in the second estimation step, to facilitate subsequent image reconstruction according to the CT projection data after summation.

[0057] Third Embodiment

[0058] Fig. 5 is a block diagram of an apparatus for data recovery of raw CT projection data provided by a third embodiment of the present invention. As shown in Fig.5, in the third embodiment of the present invention, the apparatus for data recovery of raw CT projection data comprises a region determination module 100 and at least one of the first processing module 200 and the second processing module 300. Specifically:

[0059] The region determination module 100 may be used to determine a region to be estimated and a trusted region adjacent to the region to be estimated in the raw CT projection data.

[0060] The first processing module 200 may comprise a data fitting unit 230 and a first estimation unit 250. The data fitting unit 230 may be used to perform data fitting for the CT projection data of the trusted region to obtain a space curved surface

equation. The first estimation unit 250 may be used to re-estimate the CT projection data of the region to be estimated according to the space curved surface equation.

[0061] Optionally, the first estimation unit 250 may take coordinates and CT projection values of a data point to be estimated in the region to be estimated as input values for the above mentioned space curved surface equation, and calculate output values of the space curved surface equation as the low-frequency part of the new CT projection data of the data point.

[0062] The above mentioned second processing module 300 may comprise a texture orientation information acquisition unit 310, a matching line determination unit 320 and a second estimation unit 330.

[0063] The texture orientation information acquisition unit 310 may be used to acquire multiple texture orientation information distributed in the trusted region according to the CT projection data of the trusted region.

[0064] Optionally, the texture orientation information acquisition unit 310 may acquire multiple texture orientation information distributed in the trusted region according to the high-frequency data in the CT projection data of the trusted region. The method for obtaining the high-frequency data in the CT projection data of the trusted region has been introduced in the above mentioned first embodiment and would not be repeated in details here.

[0065] Optionally, the texture orientation information acquisition unit 310 may filter the CT projection data of the trusted region with a filter to acquire multiple texture orientation information distributed in the trusted region. The above mentioned filter may comprise a Gabor filter.

[0066] The matching line determination unit 320 may be used to determine one or more matching lines in the region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information.

[0067] Optionally, the matching line determination unit 320 may determine, for each data point to be estimated, one first straight line passing through the data point. If the first straight line can rotate about the data point as a center of rotation to a matching angle, the matching line determination unit 320 may determine the first straight line at the matching angle as one matching line.

[0068] The second estimation unit 330 may be used to perform interpolation operation along the above mentioned one or more matching lines, to re-estimate the CT projection data of the region to be estimated.

[0069] In the above third embodiment, the apparatus may only include the first processing module 200 to perform data fitting for the trusted region adjacent to the region to be estimated to obtain the space curved surface equation, and to re-estimate the CT projection data of the region to be estimated according to the space curved surface equation; or the apparatus may only include the second processing module 300 to determine the matching line and to perform interpolation along the matching line, to re-estimate the CT projection data of the region to be estimated.

[0070] Fourth Embodiment

[0071] Fig. 6 is a block diagram of an apparatus for data recovery of raw CT projection data provided by a fourth embodiment of the present invention. As shown in Fig. 6, the fourth embodiment is similar to the third embodiment except that, in the fourth embodiment, the second processing module 300 may further comprise an intensity comparison unit 350 and a matching line classification unit 370. The intensity comparison unit 350 may be used to compare the data intensity at the data point corresponding to the texture orientation information matched with each matching line with a preset data intensity. The matching line classification unit 370 is used to determine a corresponding matching line as a first matching line or a second matching line based on the comparison result; for example, if the data intensity at the data point corresponding to the texture orientation information matched with any matching line is greater than or equal to the preset data intensity,

the matching line classification unit 370 determines the corresponding matching line as the first matching line; if the data intensity at the data point corresponding to the texture orientation information matched with any matching line is less than the preset data intensity, the matching line classification unit 370 determines the corresponding matching line as the second matching line. The second estimation unit 330 may only choose to perform interpolation operation along the first matching line while ignoring the second matching line.

[0072] Optionally, the apparatus for data recovery of CT raw projection data of the third embodiment may only comprise the first processing module 200 while excluding the second processing module 300, and the first processing module 200 may be specifically used to re-estimate the low-frequency data of the region to be estimated; the apparatus for data recovery of CT raw projection data of the third embodiment may also only comprise the second processing module 300 while excluding the first processing module 200, and the second processing module 300 may be specifically used to re-estimate the high-frequency data of the region to be estimated. The difference of the fourth embodiment from the third embodiment may also be that the apparatus for data recovery of CT raw projection data may comprise both the first processing module 200 and the second processing module 300, where the apparatus for data recovery of CT raw projection data may further comprise a summation processing module 600 for performing summation operation for the CT projection data estimated by the first processing module 200 and the CT projection data estimated by the second processing module 300.

[0073] Fifth Embodiment

[0074] Fig.7 is a block diagram of a CT imaging system provided by a fifth embodiment of the present invention. As shown in Fig.7, the CT imaging system comprises a bulb tube 710, a detector 720 and an apparatus 730 for data recovery of CT raw projection data. The bulb tube 710 may be used to emit X-rays to an object to be scanned, the detector 720 may be used to receive the X-rays that pass through the above mentioned object to be scanned to generate raw CT projection data, and the apparatus 730 for data recovery of raw CT projection data may be used to

perform data recovery for the raw CT projection data, to perform image reconstruction. The above mentioned apparatus 730 for data recovery of CT raw projection data may be an apparatus for data recovery of CT raw projection data in the embodiment shown in Fig.5 or Fig.6.

[0075] In the embodiments of the present invention, by determining a trusted region adjacent to a region to be estimated in raw CT projection data and performing data fitting for the CT projection data in the trusted region to obtain a space curved surface equation for recovering the CT projection data in the region to be estimated, or by determining a matching line in the region to be estimated that is matched with the texture orientation information of the CT projection trace in the trusted region and performing interpolation operation along the matching line that may represent the actual trend of the CT projection trace, the embodiments of the present invention realize interpolation operation along the CT projection trace instead of interpolation within the channel row or interpolation between channels with the same opening angle between rows, by which the recovered data is more precise and quality of the acquired CT image is better.

[0076] Some exemplary embodiments have been described in the above. However, it should be understood that various modifications may be made thereto. For example, if the described techniques are carried out in different orders, and/or if the components in the described system, architecture, apparatus or circuit are combined in different ways and/or replaced or supplemented by additional components or equivalents thereof, proper results may still be achieved. Accordingly, other implementation also falls within a protection range of the Claims.

What is claimed is:

1. A method for data recovery of raw CT projection data, comprising:

a region determination step: determining a region to be estimated and a trusted region adjacent to said region to be estimated in raw CT projection data; and

performing at least one of a first processing and a second processing;

said first processing comprising:

a data fitting step: performing data fitting for CT projection data of said trusted region to obtain a space curved surface equation;

a first estimation step: re-estimating CT projection data of said region to be estimated according to said space curved surface equation;

said second processing comprising:

a texture orientation information acquisition step: acquiring multiple texture orientation information distributed in said trusted region according to the CT projection data of said trusted region;

a matching line determination step: determining one or more matching lines in said region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information;

a second estimation step: performing interpolation operation along said one or more matching lines, to re-estimate the CT projection data of said region to be estimated.

2. The method for data recovery of raw CT projection data according to claim 1, wherein said first estimation step comprises:

taking coordinates and CT projection values of a data point to be estimated in said region to be estimated as input values for said space curved surface equation, and calculating output values of said space curved surface equation as a low-frequency part of new CT projection data of the data point.

3. The method for data recovery of raw CT projection data according to claim 1, wherein said texture orientation information acquisition step comprises:

acquiring multiple texture orientation information distributed in said trusted region according to high-frequency data in the CT projection data of said trusted region.

4. The method for data recovery of raw CT projection data according to claim 1, wherein said texture orientation information acquisition step comprises:

acquiring multiple texture orientation information distributed in said trusted region by filtering the CT projection data of said trusted region with a filter.

5. The method for data recovery of raw CT projection data according to claim 4, wherein said filter comprises a Gabor filter.

6. The method for data recovery of raw CT projection data according to claim 1, wherein each of the texture orientation information distributed in said trusted region comprises directional lines, each directional line having a specific direction; said matching line determination step comprises:

determining, for each data point to be estimated, one first straight line passing through said data point;

if said first straight line can rotate about said data point as a center of rotation to a matching angle, determining the first straight line at said matching angle as one matching line; wherein at said matching angle, the angles formed by connecting said first straight line with at least two directional lines are less than or equal to a preset angle respectively, the at least two directional lines being positioned at opposite sides of said data point to be estimated.

7. The method for data recovery of raw CT projection data according to claim 1, further comprising:

comparing a data intensity at a data point corresponding to the texture orientation information matched with each matching line with a preset data intensity;

if the data intensity at the data point corresponding to the texture orientation information matched with anyone of the matching lines is greater than or equal to said preset data intensity, determining the corresponding matching line as a first matching line;

if the data intensity at the data point corresponding to the texture orientation information matched with anyone of the matching lines is less than said preset data intensity, determining the corresponding matching line as a second matching line;

performing interpolation operation along said one or more matching lines comprises: only choosing to perform interpolation operation along said first matching line

8. The method for data recovery of raw CT projection data according to claim 1, wherein said method for data recovery of raw CT projection data comprises said first processing and second processing and further comprises:

performing summation for the CT projection data estimated in said first processing and the CT projection data estimated in said second processing.

9. An apparatus for data recovery of raw CT projection data, comprising:

a region determination module for determining a region to be estimated and a trusted region adjacent to said region to be estimated in raw CT projection data; and

at least one of a first processing module and a second processing module;

said first processing module comprising:

a data fitting unit to perform data fitting for CT projection data of said trusted region to obtain a space curved surface equation;

a first estimation unit to re-estimate CT projection data of said region to be estimated according to said space curved surface equation;

said second processing module comprising:

a texture orientation information acquisition unit to acquire multiple texture orientation information distributed in said trusted region according to the CT projection data of said trusted region;

a matching line determination unit to determine one or more matching lines in said region to be estimated according to each of the texture orientation information, each matching line passing through at least one data point to be estimated and being matched with at least one texture orientation information;

a second estimation unit to perform interpolation operation along said one or more matching lines, to re-estimate the CT projection data of said region to be estimated.

10. The apparatus for data recovery of raw CT projection data according to claim 9, wherein said texture orientation information acquisition unit is to acquire multiple texture orientation information distributed in said trusted region according to high-frequency data in the CT projection data of said trusted region.

11. The apparatus for data recovery of raw CT projection data according to claim 9, wherein said first estimation unit is to take coordinates and CT projection values of a data point to be estimated in said region to be estimated as input values for said space curved surface equation, and to calculate output values of said space curved surface equation as a low-frequency part of new CT projection data of the data point.

12. The apparatus for data recovery of raw CT projection data according to claim 9, wherein said texture orientation information acquisition unit acquires multiple

texture orientation information distributed in said trusted region by filtering the CT projection data of said trusted region with a filter.

13. The apparatus for data recovery of raw CT projection data according to claim 12, wherein said filter comprises a Gabor filter.

14. The apparatus for data recovery of raw CT projection data according to claim 9, wherein each texture orientation information distributed in said trusted region comprises directional lines, each directional line having a specific direction, said matching line determination unit is to determine one first straight line passing through said data point for each data point to be estimated, and the first straight line at said matching angle is determined as one matching line if said first straight line can rotate about said data point as a center of rotation to a matching angle; wherein at said matching angle, the angles formed by connecting said first straight line with at least two directional lines are less than or equal to a preset angle respectively, the at least two directional lines being positioned at opposite sides of said data point to be estimated.

15. The apparatus for data recovery of raw CT projection data according to claim 9, wherein said second processing module further comprises:

an intensity comparison unit to compare a data intensity at a data point corresponding to the texture orientation information matched with each matching line with a preset data intensity;

a matching line classification unit to, if the data intensity at the data point corresponding to the texture orientation information matched with anyone of the matching lines is greater than or equal to said preset data intensity, determine the corresponding matching line as a first matching line; and to, if the data intensity at the data point corresponding to the texture orientation information matched with anyone of the matching lines is less than said preset data intensity, determine the corresponding matching line as a second matching line;

said second estimation unit is to: only choose to perform interpolation operation along said first matching line.

16. The apparatus for data recovery of raw CT projection data according to claim 9, wherein the apparatus for data recovery of raw CT projection data comprises said first processing module and said second processing module, and further comprises a summation processing module to perform summation processing for the CT projection data estimated by said first estimation unit and the CT projection data estimated by said second estimation unit.

17. A CT imaging system comprising a bulb tube to emit X-rays to an object to be scanned, a detector to receive the X-rays that pass through said object to be scanned to generate said raw CT projection data and an apparatus for data recovery of CT raw projection data according to anyone of claims 9-16.

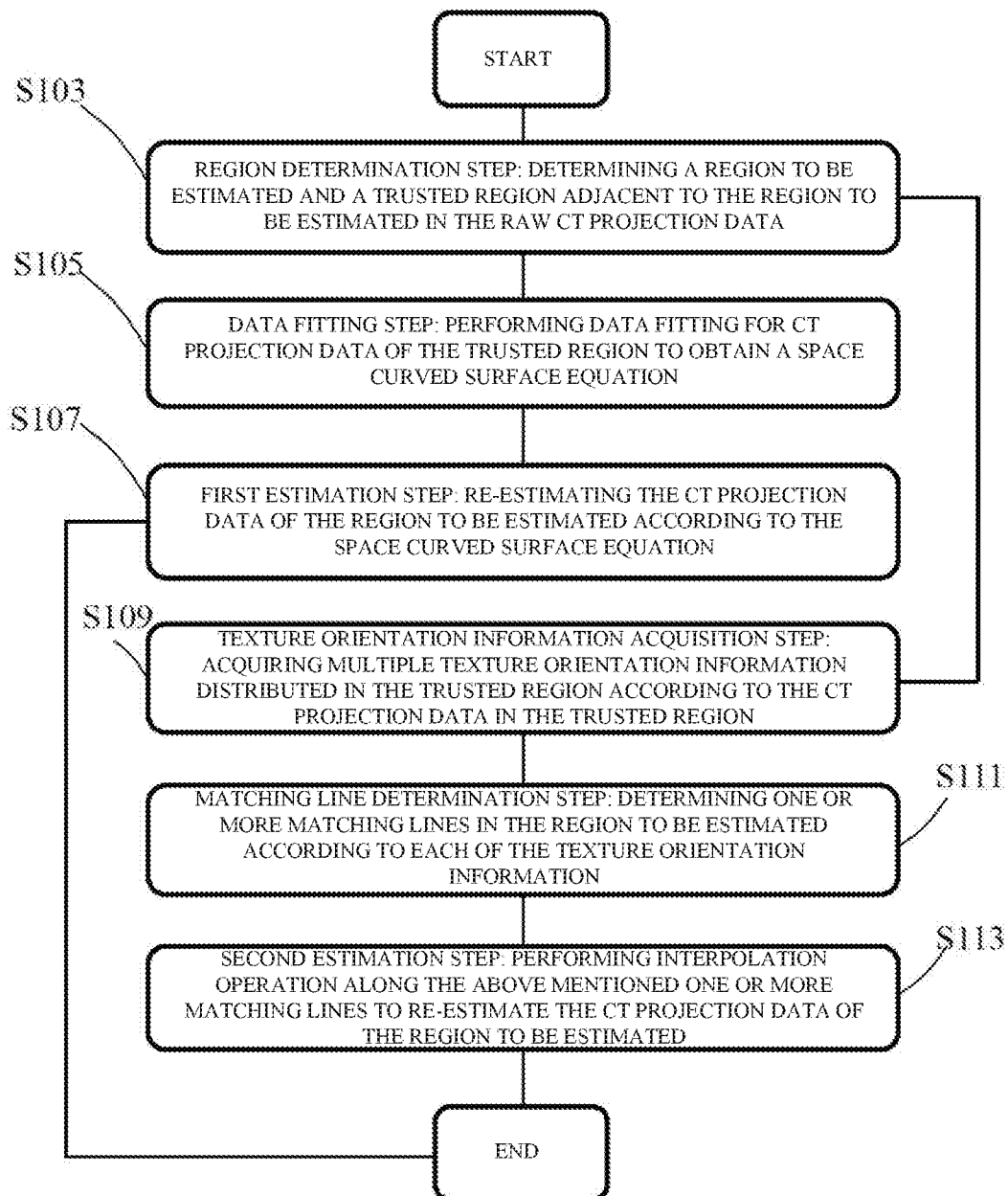


FIG.1

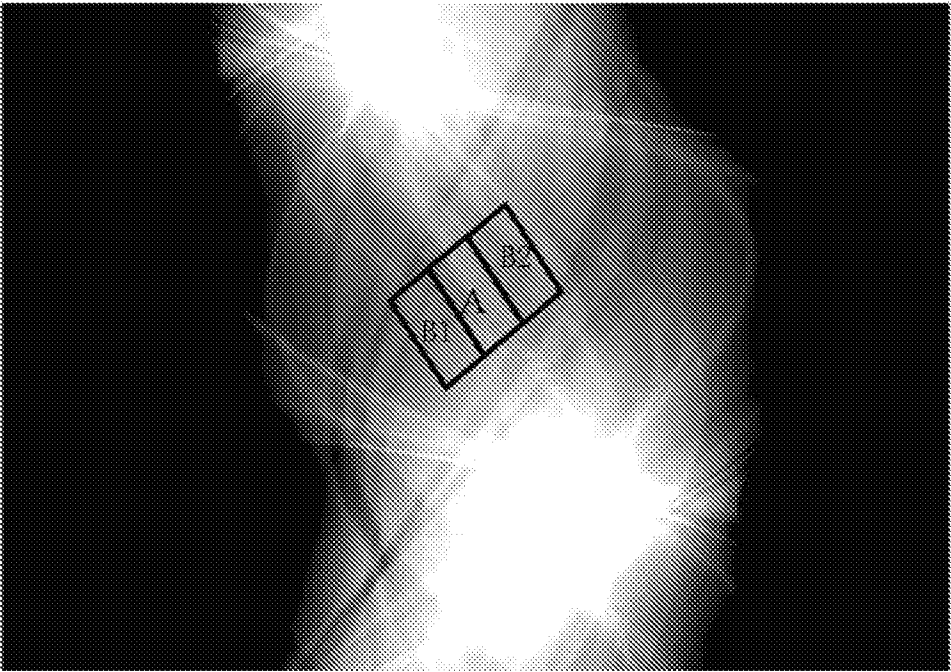


FIG.2

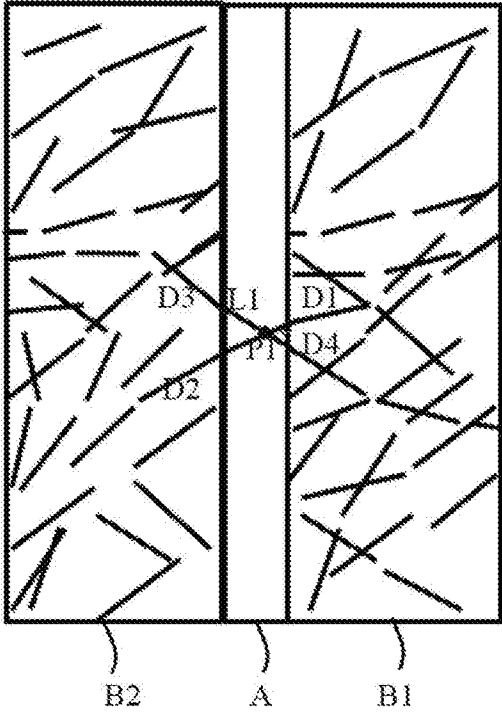


FIG.3

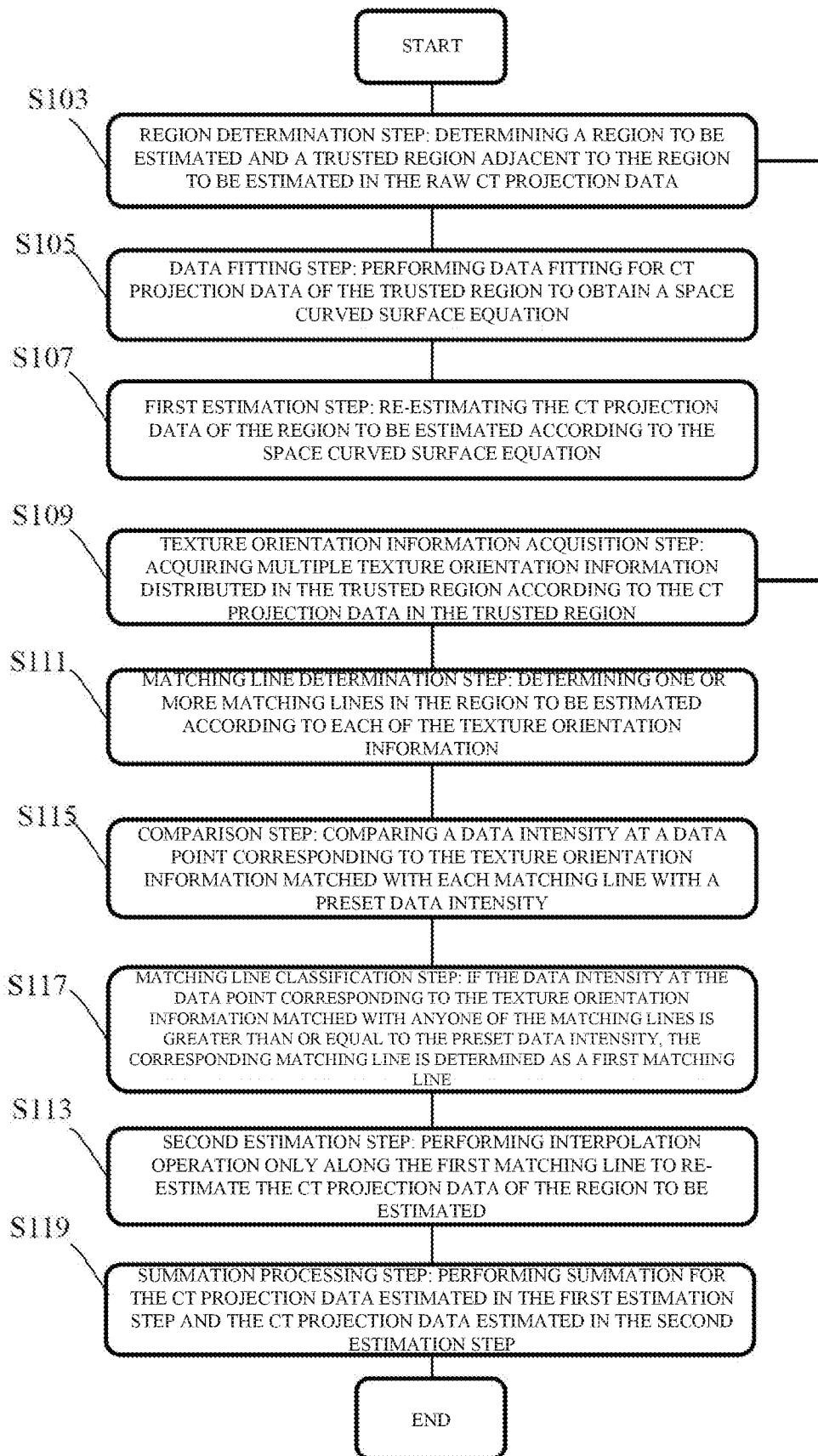


FIG.4

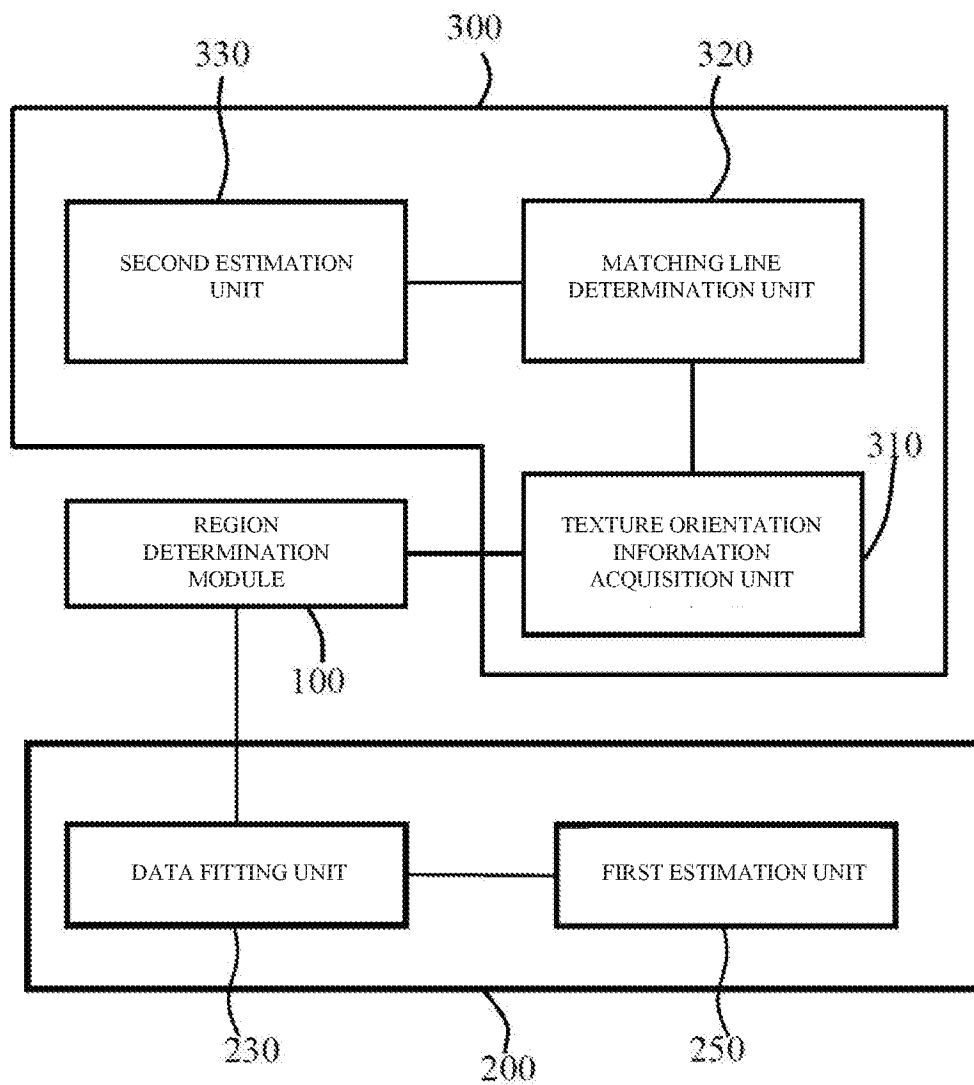


FIG.5

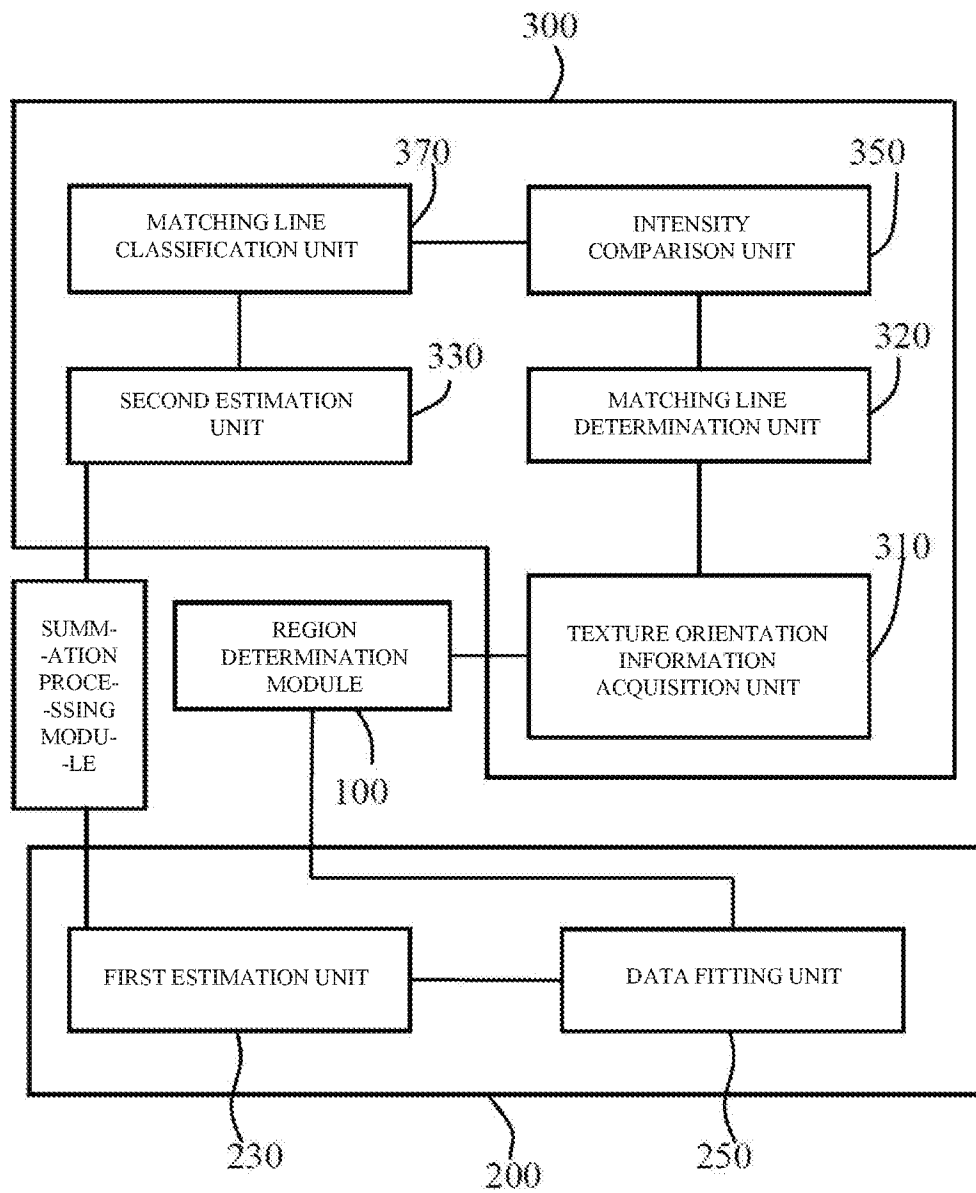


FIG.6

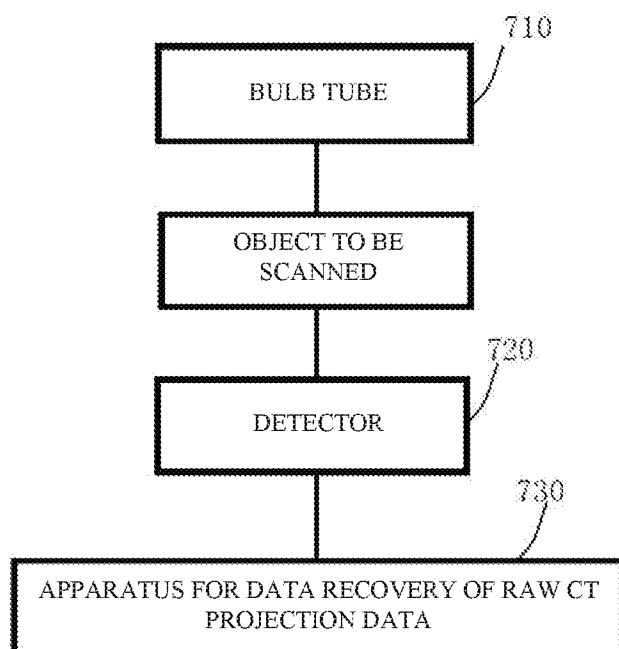


FIG.7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US16/38476

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 6/02; G01T 1/29; G06T 11/00 (2016.01)

CPC - A61B 6/027, 6/5235, 6/5258; G01T 1/2985; G06T 11/005

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): A61B 6/02; G01T 1/29; G06T 11/00 (2016.01)

CPC: A61B 6/027, 6/5235, 6/5241, 6/5258; G01T 1/2985; G06T 11/005, 2211/40, 2211/424

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google; Google Scholar; EBSCO; KEYWORDS: data recovery CT projection data interpolation estimate pixel points reconstructed image overlapped region projection tracks texture orientation trace trajectory

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/0056437 A1 (PACK, J. et al.) March 6, 2008; figures 1-2; paragraphs [0028, 0039-0040-0045, 0063]	1-17
A	US 2007/0248255 A1 (CHEN, G.) October 25, 2007; figures 6, 10; paragraphs [0025-0037]	1-17
A	US 2013/0308745 A1 (GOSHEN, L.) November 21, 2013; figures 1, 3; paragraphs [0031-0037]	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

23 August 2016 (23.08.2016)

Date of mailing of the international search report

14 SEP 2016

Name and mailing address of the ISA/

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Shane Thomas

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774